MATH AND SCIENCE @ WORK

AP* BIOLOGY Educator Edition

RESPIRATION IN SPACE FLIGHT

Note: This problem is related to the chemistry problems *Carbon Dioxide Removal – Stoichiometry* and *Carbon Dioxide Removal – Thermodynamics* in the Math and Science @ Work series.

Instructional Objectives

Students will

- recall materials, procedures, and results of required cellular respiration lab;
- analyze respiration rates and metabolic activity from graphical data;
- relate gas production/consumption to respiration/metabolism;
- evaluate physiological impact of changes in O_2/CO_2 concentrations on various human systems; and
- propose changes needed to maintain O_2/CO_2 levels for crew health.

Degree of Difficulty

This problem may be challenging because students need to relate molecular cellular respiration process to human physiology. If your school doesn't offer Anatomy/Physiology or you would like to simplify the question, one option is to approach the topic from a cellular/molecular perspective only and eliminate questions C and D dealing with body systems. Another option is to have students research the physiological symptoms in questions C and D.

- For the average AP Biology student the problem may be at an advanced difficulty level.

Class Time Required

This problem requires 45-75 minutes.

- Introduction: 5-10 minutes
- Student Work Time: 20-40 minutes
  If adaptations are made to have students research physiological symptoms, students will require more than 20 minutes to answer the questions.
- Post Discussion: 20-25 minutes

Grade Level
10-12

Key Topic
Evaluating Cellular Energetics; Synthesis and Application of Lab 5

Degree of Difficulty
Advanced

Teacher Prep Time
30 minutes

Class Time Required
45-70 minutes

Technology
Calculator

AP Course Topics
Molecules and Cells:
- Cellular Energetics

Organisms and Populations:
- Structure and Function of Plants and Animals

NSES
Science Standards
- Physical Science
- Life Science
- Science in Personal and Social Perspectives
- History and Nature of Science

Background

This problem is part of a series of problems that apply Math and Science @ Work in NASA's Space Shuttle Mission Control Center.

Since its conception in 1981, NASA has used the space shuttle for human transport, the construction of the International Space Station (ISS), and to research the effects of space on the human body. One of the keys to the success of the Space Shuttle Program is the Space Shuttle Mission Control Center (MCC). The Space Shuttle MCC at NASA Johnson Space Center uses some of the most sophisticated technology and communication equipment in the world to monitor and control the space shuttle flights.

Within the Space Shuttle MCC, teams of highly qualified engineers, scientists, doctors, and technicians, known as flight controllers, monitor the systems and activities aboard the space shuttle. They work together as a powerful team, spending many hours performing critical simulations as they prepare to support preflight, ascent, flight, and reentry of the space shuttle and the crew. The flight controllers provide the knowledge and expertise needed to support normal operations and any unexpected events.

One of the flight control positions in the Space Shuttle MCC is the Emergency, Environmental, and Consumables Manager (EECOM). The EECOM flight controller monitors and regulates the cabin atmosphere which includes gas concentrations and pressures within the space shuttle cabin. Maintaining these parameters ensures a habitable cabin atmosphere and temperature on board the space shuttle much like the atmosphere here on Earth. These conditions allow the crew to work in a "shirt sleeve" environment while in the cabin (i.e. the crew can wear normal clothing rather than the protective clothing that is necessary outside of the cabin area).

Figure 1: Astronauts Thomas D. Jones, mission specialist, and Mark L. Polansky, pilot, change out lithium hydroxide canisters on the mid deck of the Earth-orbiting Space Shuttle Atlantis

Figure 2: Astronaut Sandra Magnus uses a computer on the middeck of Space Shuttle Endeavour during flight activities.

Air is circulated in the space shuttle cabin using fans that force the air through cabin air loops where the air is conditioned. Conditioning the air involves a series of processes that remove dust particles, heat, humidity, and carbon dioxide (CO_2). The absorption method used to remove carbon dioxide from the air involves a chemical reaction using lithium hydroxide (LiOH) as the sorbent. Lithium hydroxide is an attractive choice for space flight because of its high absorption capacity for carbon dioxide and the small amount of heat produced in the reaction. Lithium hydroxide canisters are located in mid deck of

the space shuttle and their replacement is a daily activity during space shuttle flights. There is a potential for some toxicity within the space shuttle cabin due to lithium hydroxide dust that could be ingested by the crew. Before a space shuttle mission, EECOM flight controllers and crewmembers receive training that ensures correct precautions and procedures are followed while replacing the lithium hydroxide canisters.

AP Course Topics

Molecules and Cells

- Cellular Energetics:
  - Coupled reactions
  - Fermentation and cellular respiration

Organisms and Populations

- Structure and Function of Plants and Animals:
  - Structural, physiological, and behavioral adaptations
  - Response to the environment

NSES Science Standards

Physical Science

- Chemical reactions

Life Science

- The cell
- Matter, energy, and organization in living systems

Science in Personal and Social Perspectives

- Personal and community health

History and Nature of Science

- Science as a human endeavor

Problem

Figure 3 is a graph that depicts the concentrations of CO_2 in the space shuttle over a 4 day period. During each 24 hour period, an estimated 3.5 canisters of LiOH are required to remove the CO_2 produced by the crew (this number is based on a crew of 7 people). Each peak and valley in the graph represents a LiOH changeout. The peak represents the installation of the canister(s) and the valley represents the canister(s) being saturated with CO_2. Each LiOH changeout could include either one or two canisters being replaced. The larger peaks shown in Figure 3 represent the replacement of two canisters while the smaller peaks represent only one canister replacement. If a high level of metabolic oxygen consumption is predicted, a LiOH canister would be installed prior to the high metabolic rates in order to preclude reaching a high level of partial pressure of CO_2. In the graph, periods of high metabolic consumption are represented by the slope of increase in CO_2. Before a flight, EECOM flight controllers use data collected from previous missions to predict the number of LiOH canisters that will be needed and the time intervals of their installation to ensure the health and safety of the crew. If actual data shows higher or lower than predicted, the EECOM flight controller will make a recommendation of adding or removing a canister changeout.

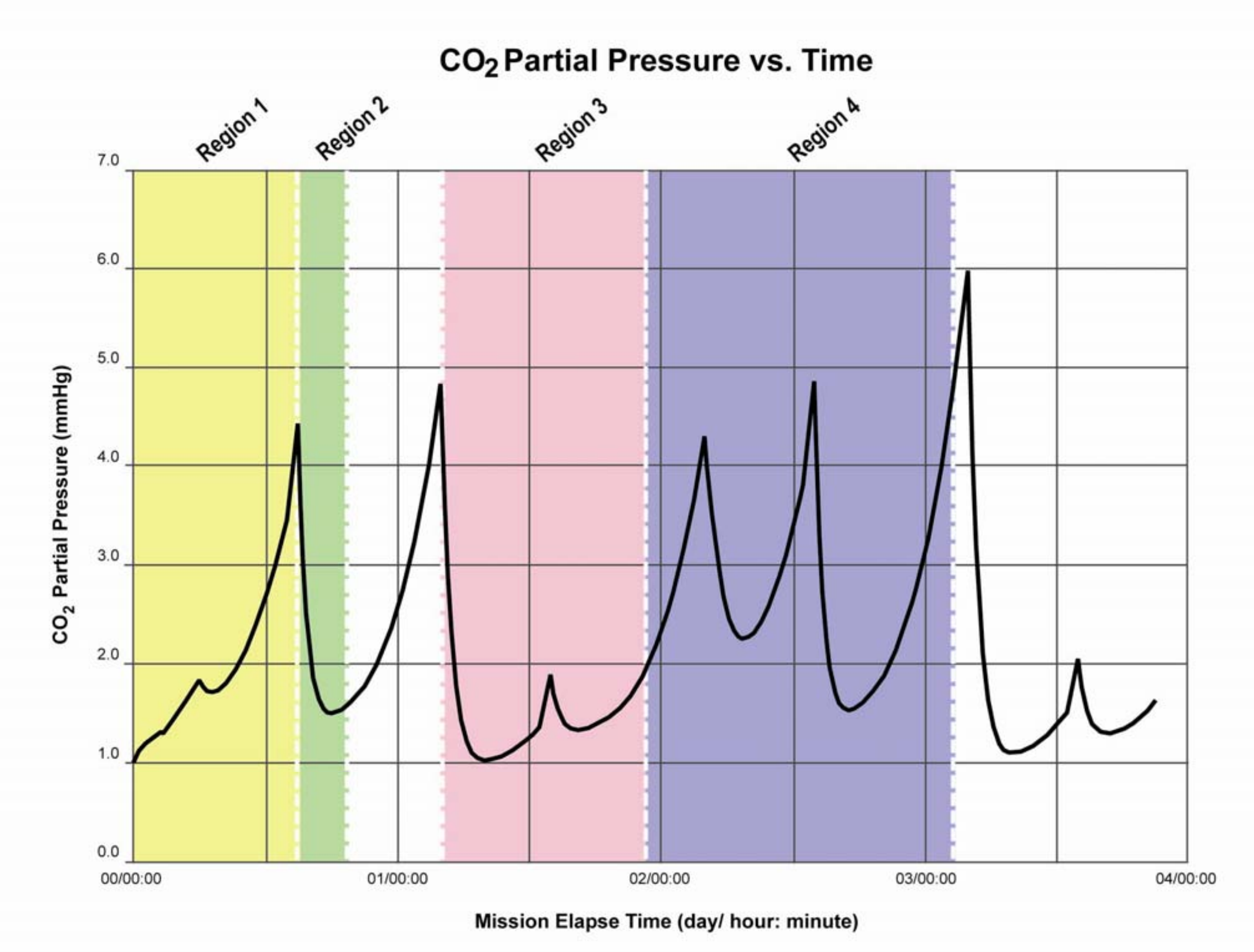

Figure 3: Partial pressures of CO_2 in the space shuttle cabin during a four day period.
Note that this is a replicated graph using data from previous space shuttle missions.

A. Name two methods for measuring cellular respiration. Which method is Figure 3 depicting?

B. Using Figure 3, describe the metabolic events represented in each region. Explain your answer in terms of cellular respiratory function, physiological respiratory function and activity, and environmental gas balance and pressures.

   I. Region 1

   II. Region 2

   III. Region 3

   IV. Region 4

C. Suppose convection currents (air flow due to temperature and pressure changes) were not forced using fans as described in the provided background. List the symptoms (with causes) that the crew members might exhibit as a result.

D. Suppose in an emergency situation there is an unexpected drop in oxygen (O_2) partial pressure detected by the EECOM flight controller. Crewmembers begin to exhibit symptoms similar to those of high altitude mountain climbers that could be from one or a combination of gas factors.

Identify how the gas levels cause the physiological symptoms in two of the four systems: circulatory, respiratory, nervous, and muscular.

Solution Key (One Approach)

A. Name two methods for measuring cellular respiration. Which method is Figure 3 depicting?

The graph in Figure 3 is an example of using CO_2 as a way to measure respiration. Determining the consumption of oxygen and calculating the release of energy are two other methods of measuring respiration.

Students might also use the following equation to help them in explaining this problem and should receive an extra point if they do.

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ $\Delta G = -686$ kcal/mole glucose (- 2870 kJ/mole glucose)

B. Using Figure 3, describe the metabolic events represented in each region. Explain your answer in terms of cellular respiratory function, physiological respiratory function and activity, and environmental gas balance and pressures.

Analysis of Figure 3 will vary but it should reflect an understanding of the direct relationship between an increase in metabolic activity and the subsequent increase in CO_2 production. The following points may be included in student's analysis of each region.

I. Region 1

This region illustrates the cumulative effect of CO_2 production and O_2 consumption in the mitochondria as glucose is converted into adenosine triphosphate (ATP) energy for cellular function. As CO_2 concentration increases, the concentration of O_2 decreases, as it is consumed in the electron transport chain as the final electron acceptor.

II. Region 2

This region illustrates a sharp decline in the partial pressure of CO_2 from 4.75 mm Hg to 1.0 mm Hg, consistent with of the changeout of a new LiOH canister. LiOH removes the CO_2 from the cabin atmosphere just as potassium hydroxide (KOH) removed CO_2 in the AP experimental lab respirometers.

Removal of CO_2 gas to form a precipitant actually contributes to a minimal drop in cabin gas pressure as well as decreasing the CO_2 concentration in the internal atmosphere.

III. Region 3

This region starts with a LiOH canister changeout. The low level of carbon CO_2 partial pressures following the changeout would imply low metabolic activity from the crew which could be explained by a crew sleeping period. The second small peak is another canister changeout followed by a higher metabolic activity which elevated the CO_2 levels in the cabin. This could be the result of a period of exercise by the crew.

IV. Region 4

This region depicts an area of relatively high metabolic activity by the crew. As activity increases the cells require more energy (glucose) and the rate of aerobic respiration in the mitochondria will yield increases in partial pressure of CO_2 (just as germinating peas consumed more oxygen in the AP lab). The sudden drops in CO_2 partial pressure shown in Figure 3 are due to LiOH canister changeouts.

Students may also include in their explanation one of the following points and should receive additional credit:

- **Reference to AP Lab (5); cellular respiration:** This lab measures the oxygen production in peas. As the metabolic activity of the peas increased, oxygen consumption increased with a corresponding displacement of water volume inside the respirometer.
- **Similarity of the space shuttle to a respirometer:** The space shuttle is a closed system just like a respirometer. As one gas decreases, the other gas increases.

C. Suppose convection currents (air flow due to temperature and pressure changes) were not forced using fans as described in the provided background. List the symptoms (with causes) that the crew members might exhibit as a result.

Without the normal atmospheric flow caused by differences in temperature and pressure on the gases, CO_2 “pockets” can form even though total CO_2 is within acceptable range. A crewmember working in one of these pockets may experience excessive CO_2 intake.

Symptoms of exposure to high levels of CO_2 include headache, dizziness, fatigue, and visual/hearing dysfunction. Exposure to extreme levels can cause unconsciousness or death within minutes of exposure.

Note to Instructor: If students have not studied physiological symptoms, refer to adaptations instructors may want to make in the Degree of Difficulty section on page 1 of this document.

D. Suppose in an emergency situation there is an unexpected drop in O_2 partial pressure detected by the EECOM flight controller. Crewmembers begin to exhibit symptoms similar to those of high altitude mountain climbers that could be from one or a combination of gas factors. Identify how the gas changes are causing the physiological symptoms in two of the four systems: circulatory, respiratory, nervous, and muscular.

Problems with cabin depressurization lower the O_2 available for respiration. Increase in the metabolic consumption of oxygen leads to an increase in the CO_2. Dangers associated with increases in CO_2 have been discussed. Reduction in O_2 leads to a collection of symptoms referred to as hypoxia. The following are symptoms that may result:

Muscular System – lactic acid build up and fatigue as oxygen to cells decreases and anaerobic respiration increases.

Circulatory System – vasodilation when low O_2 in arteries leads to efforts to increase O_2 delivery rate.

Respiratory System – vasoconstriction and shortness of breath occur due to lack of proper oxygenation.

Nervous System – varies with person, feelings of euphoria, headache, fatigue, confusion, decrease in motor control, cognitive disturbances with tasks and memory, fainting, cessation of brain stem reflexes, death.

Note to Instructor: If students have not studied physiological symptoms, refer to adaptations instructors may want to make in the Degree of Difficulty section on page 1 of this document.

Scoring Guide

10 points total

* There are 3 additional points possible; however, students should not receive more than 10 total points for the problem, or more than the allotted points per question.

Question		**Distribution of points**
A	*2 points*	1 point for identifying method from graph 1 point for naming another method ** 1 additional point given for referencing equation noted in solution*
B	*4 points*	1 point for each area of graph described correctly ** 2 additional points could be given, 1 for referencing respiratory lab, and 1 for noting similarity of space shuttle to respirometer*
C	*2 points*	1 point for listing the symptoms 1 point for listing the cause
D	*2 points*	1 point for listing the effects within a system (1 point for each system)

Contributors

This problem was developed by the Human Research Program Education and Outreach (HRPEO) team with the help of NASA subject matter experts and high school AP instructors.

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